Wiring Up Silicon Nanostructures for High Energy Lithium Ion Battery Anodes

Yi Cui

Stanford University

June 17, 2014

Project ID #ES148

Overview

Timeline

- Start: Jan 1, 2011
- End: Dec. 31, 2014
- Percent complete: 85%

Budget

- Total project funding
  $1,200k from DOE
- Funding received in FY12
  $300k
- Funding for FY13
  $300k
- Funding for FY14
  $300k

Barriers

Barriers of batteries

- Low energy density
- High cost
- Cycle and calendar life

Targets: high energy electrode materials and cells

Partners

- Collaboration
  - BATT program PI's
  - PNNL: In-situ TEM
  - SLAC: In-situ X-ray
  - UT Austin: Prof. Korgel,materials
  - Stanford: Prof. Nix, mechanics; Prof. Bao, materials.
  - Amprius Inc.

Project Objective and Relevance

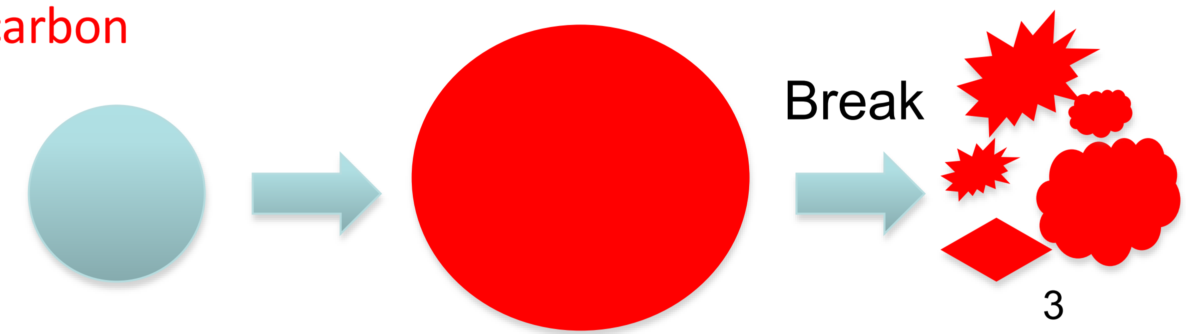
Objective

- To develop Si anodes with 10x specific charge capacity to replace the existing C anodes for high energy Li ion batteries for transportation, relevant to VT Program.
- To Understand and design nanostructure Si can address the challenging issues caused by the large volumetric expansion and provide a good cycle life.
- To Develop scalable low-cost methods for nanostructured Si anodes.

For Si: volume expansion by 4 times

Si: 4200 mAh/g, 10X of carbon

$Si \longleftrightarrow Li_{4.4}Si$

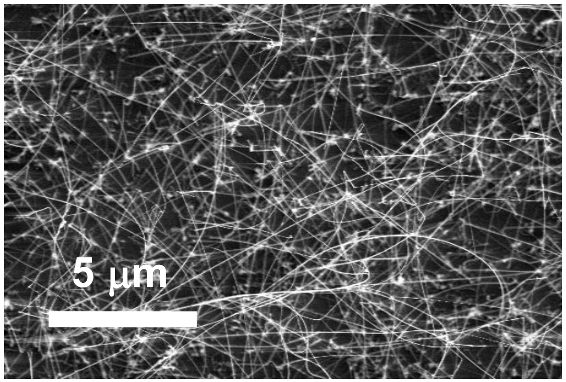


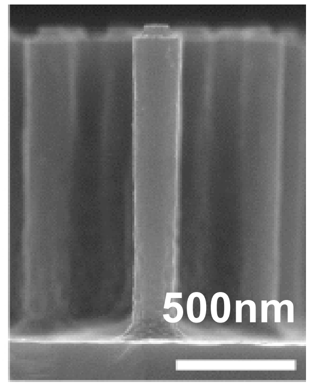
Milestones for FY13 and 14

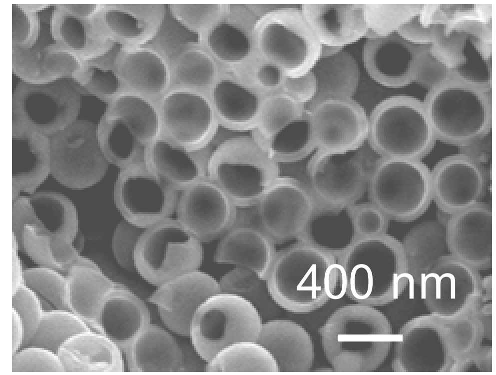
Month/year	Milestones
1/2013	Develop low cost and scalable Si yolk-shell nanostructures with stable cycle life (completed)
4/2013	Develop low-cost synthesis of Si nanoparticles from renewable sources (completed)
7/2013	Optimize nano/micro particle electrodes for high capacity, >1000 cycles, >99.7% CE (completed)
10/2012	Use in-situ TEM and ex-situ SEM to test critical size and rate for fracture for crystalline, polycrystalline, and amorphous Si nanostructures (completed)
1/2014	Utilize Si micro-sized particles as an anode with capacity > 1500 mAh/g, and cycle life >100 cycles. (completed)
4/2014 Go-no go	Stop Layer-by-layer deposition method for assembling hierarchical electrode structure if the assembly can not provide areal capacity higher than 2 mAh/cm2 (completed)
7/2014	Complete In-situ TEM and ex-situ SEM studies of two or multiple Si nanostructures during lithiation/delithiation to understand how neighboring particles affect each other and volume changes. (on schedule)

Approach/Strategy

Advanced nanostructured Si materials design and synthesis







Structure and property characterization

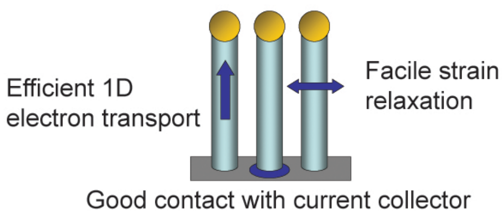
- Ex-situ transmission electron microscopy
- In-situ transmission electron microscopy
- Ex-situ scanning electron microscopy

Electrochemical testing

- Coin cells and pouch cells.
- A set of electrochemical techniques.

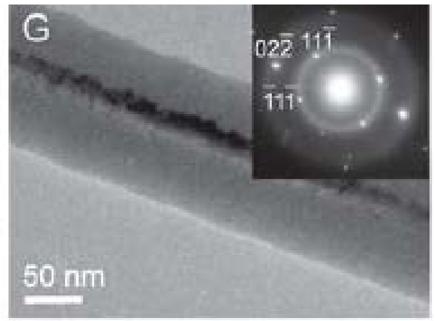
Previous Results on Silicon Nanowire Anodes

Gen 1: Nanowire



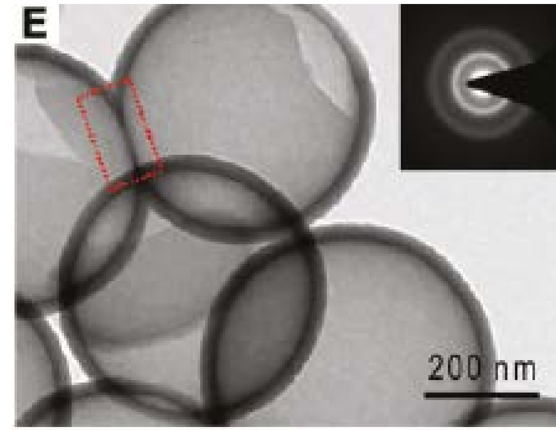
Nature Nanotechnology, 3, 31 (2008)

Gen 2: Core-Shell Nanowire



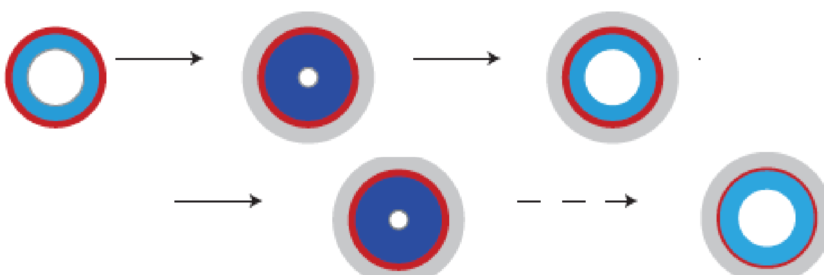
Nano Letters, 9, 491 (2009)

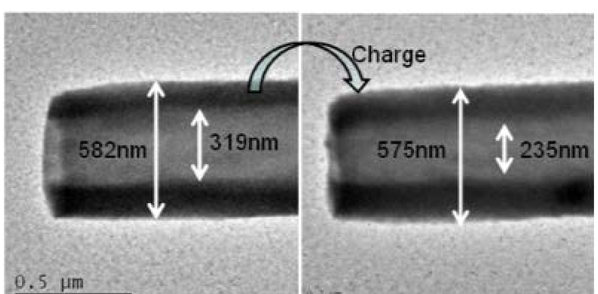
Gen 3: Hollow



Nano Letters, 11, 2949 (2011)

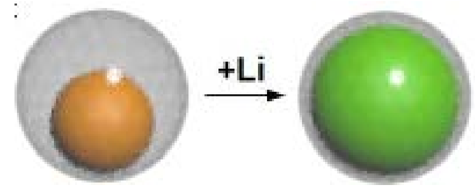
Gen 4: Double-walled hollow

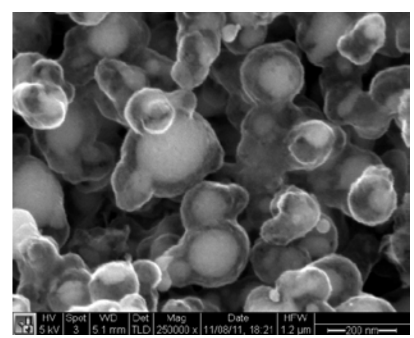


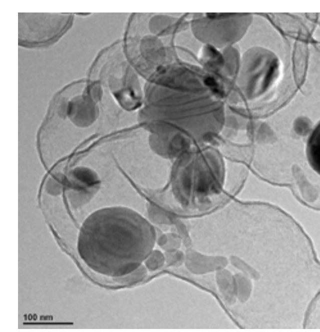


Nature Nanotechnology, 7, 310 (2012)

Gen 5: Yolk-shell





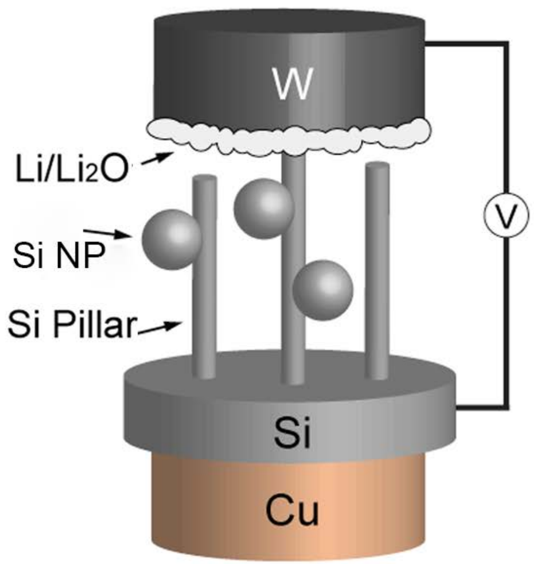


Nano Letters, 12, 3315 (2012)

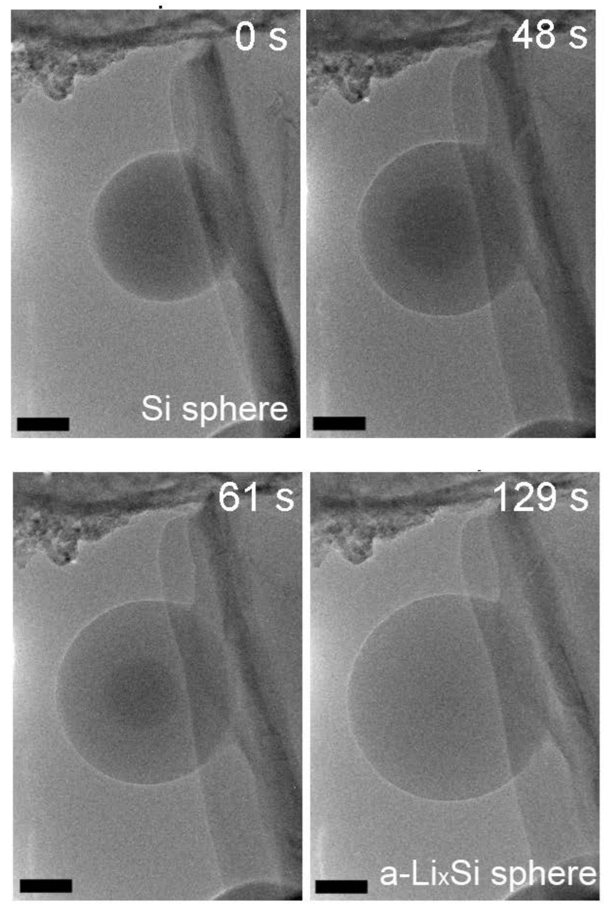
Accomplishment

In-situ TEM for amorphous Si nanoparticles

- No fracture up to 800 nm



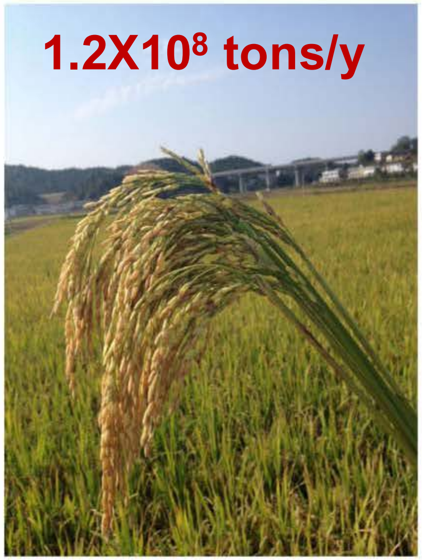
In-Situ TEM device

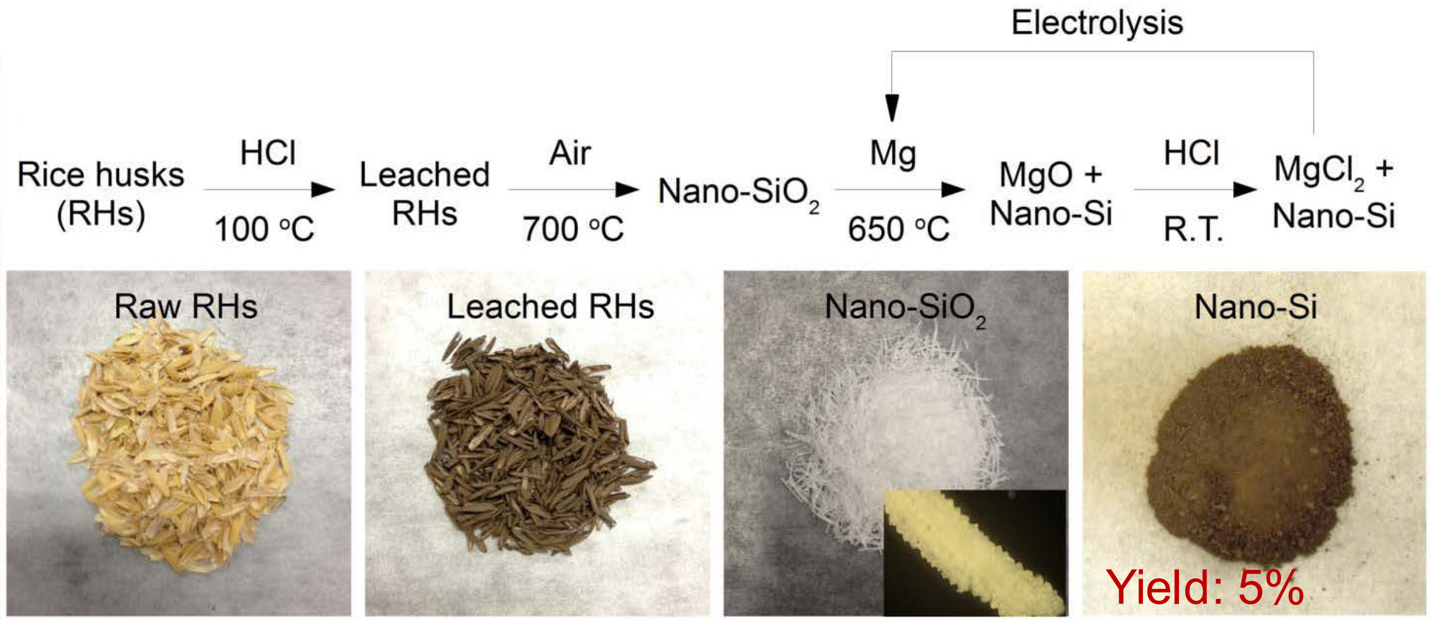


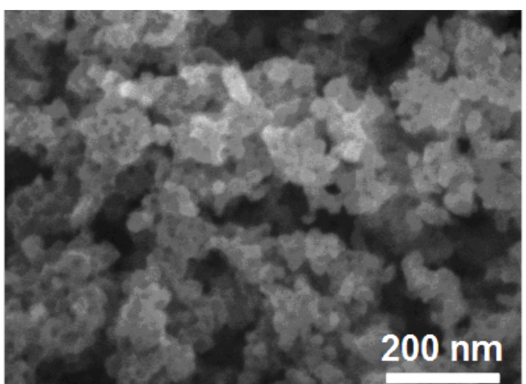
Cui group, Nano Letters, 13, 758 (2013)

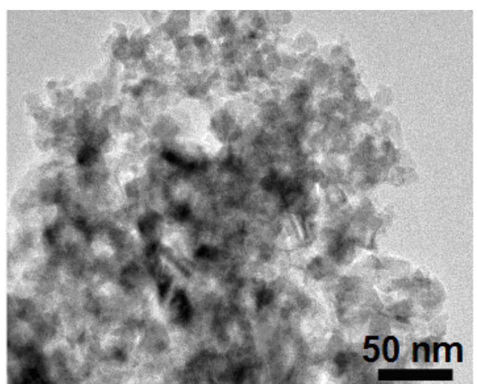
Accomplishment

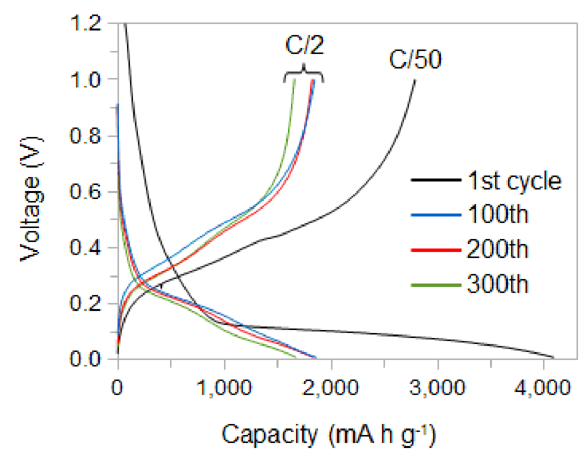
Si nanoparticles from abundant and cheap Source: rice husk









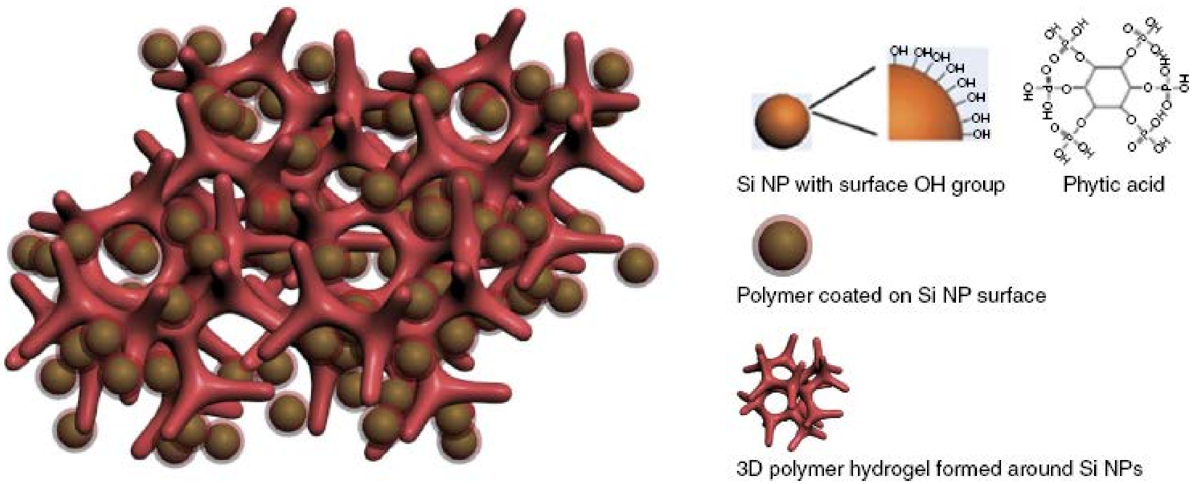


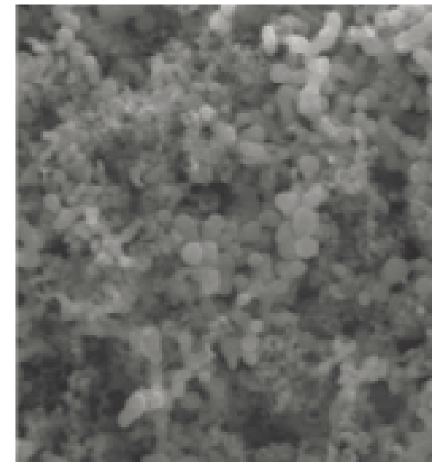
Cui group, Scientific Reports, DOI: 10.1038/srep01919 (2013)

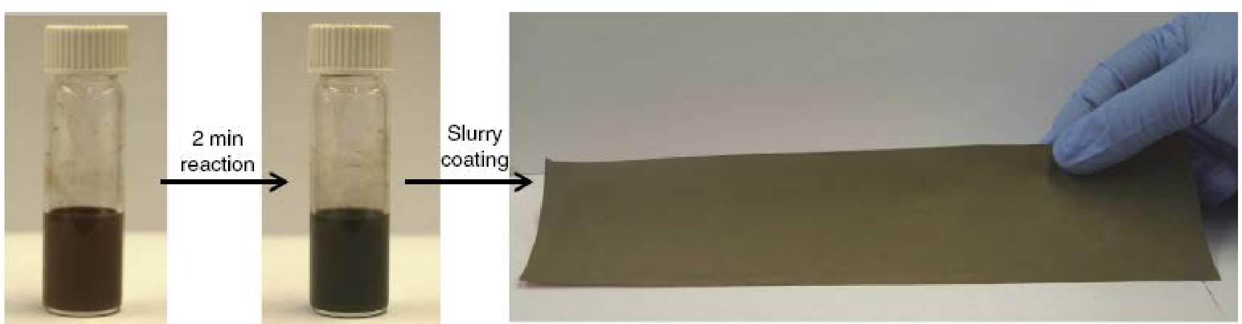
Accomplishment

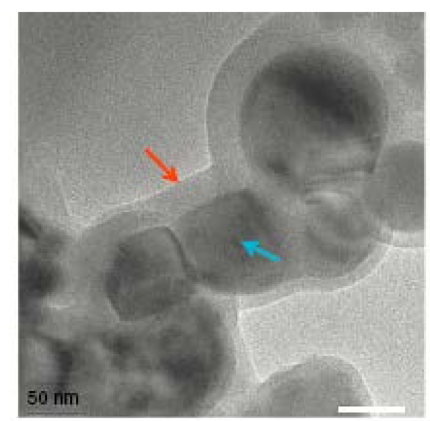
Incorporation of conducting hydrogel into Si nanoparticle anodes

-Preparation and morphology





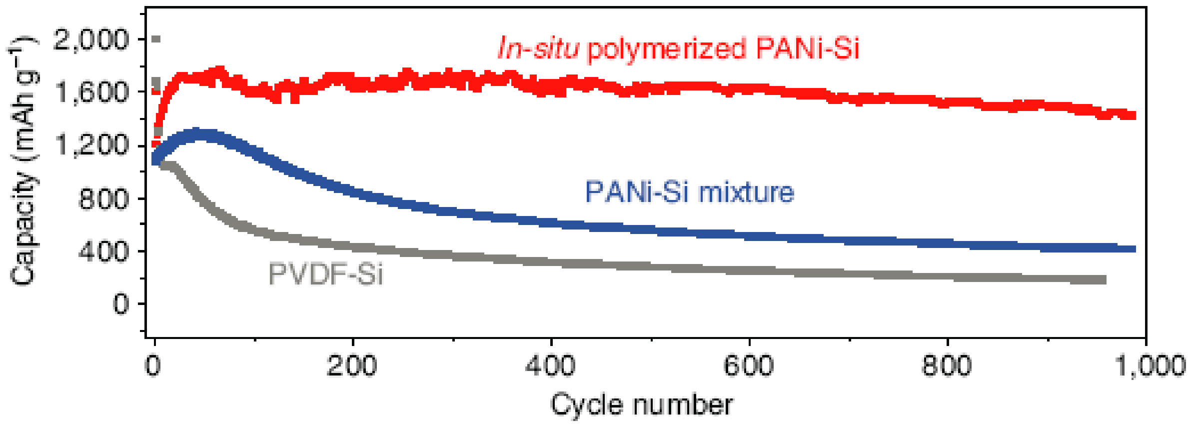


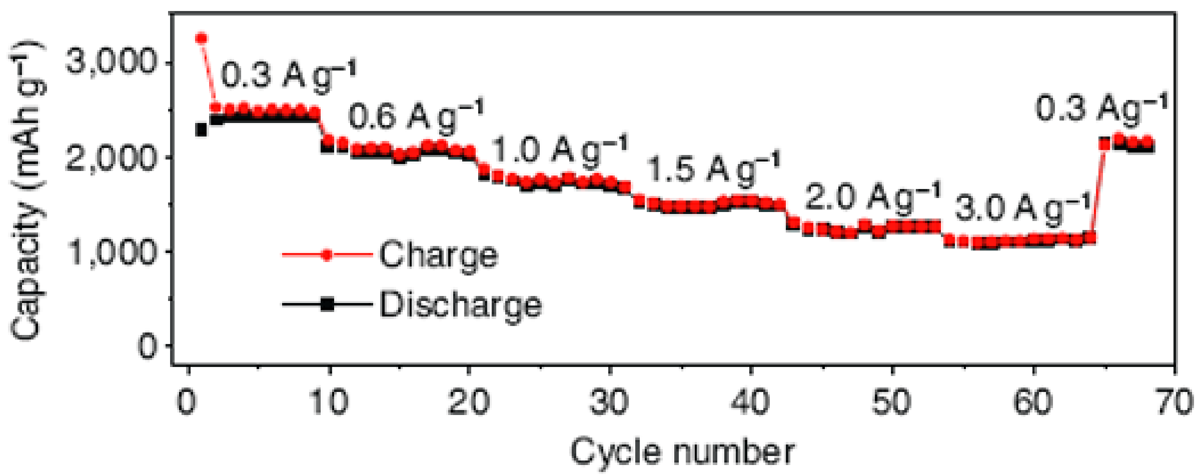


Cui group, Nature Communications, DOI: 10.1038/ncomms2941 (2013)

Accomplishment

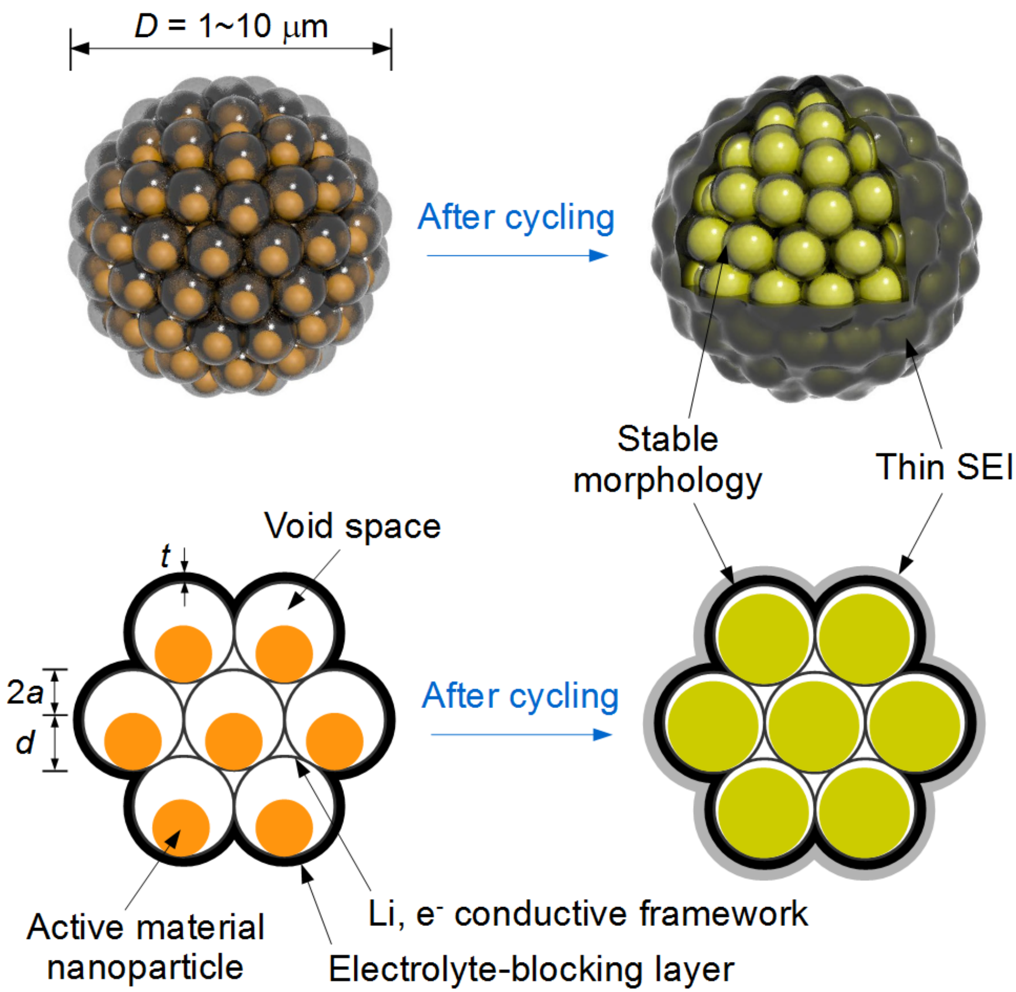
-Battery performance

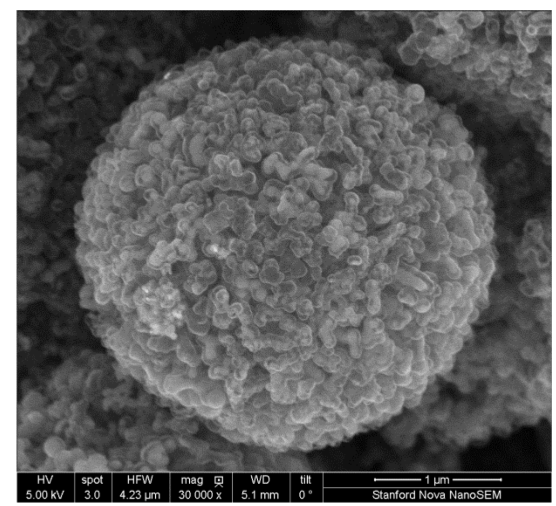




Accomplishment

pomegranate-inspired design for Si anode

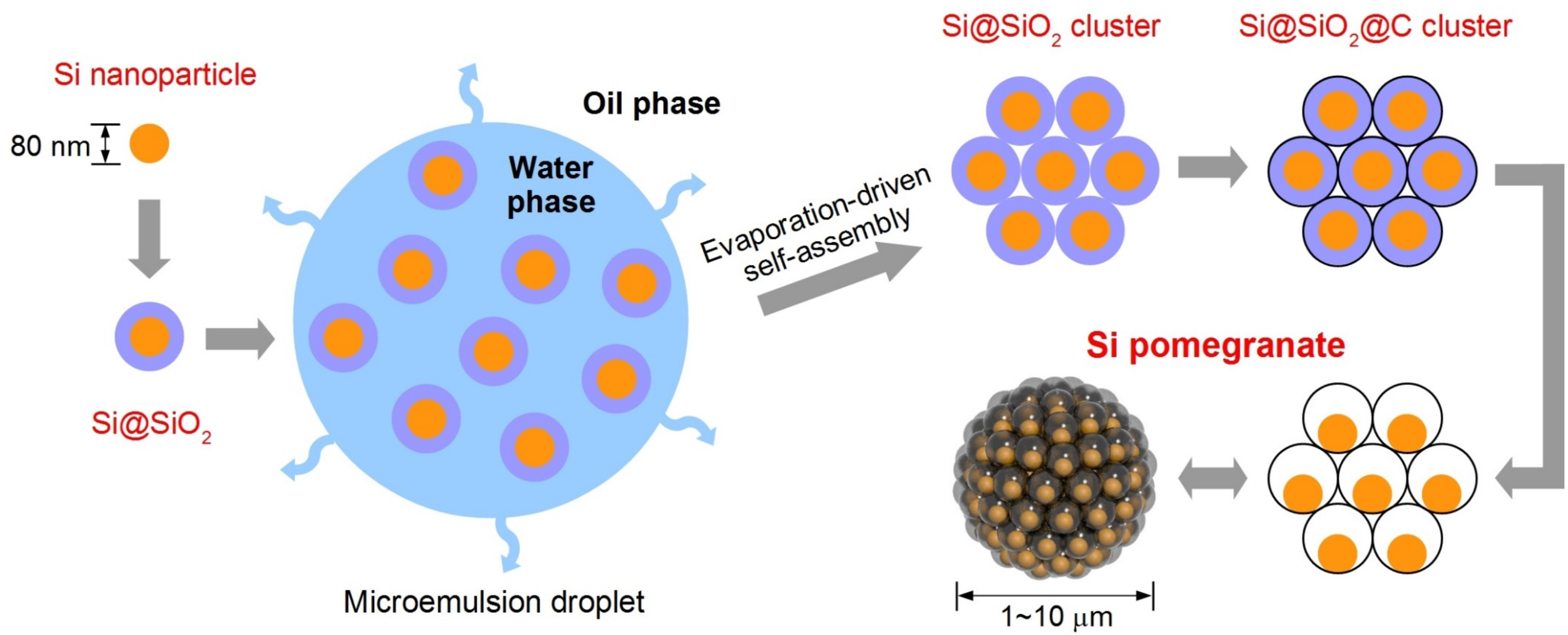


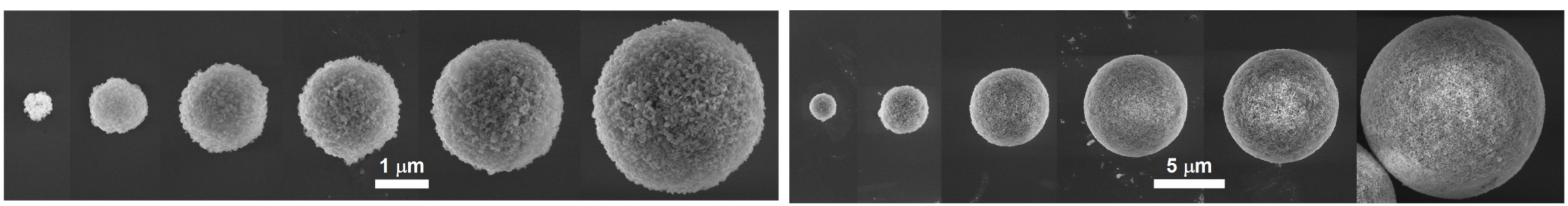


Cui group, Nature Nanotechnology, 9, 187 (2014)

Accomplishment

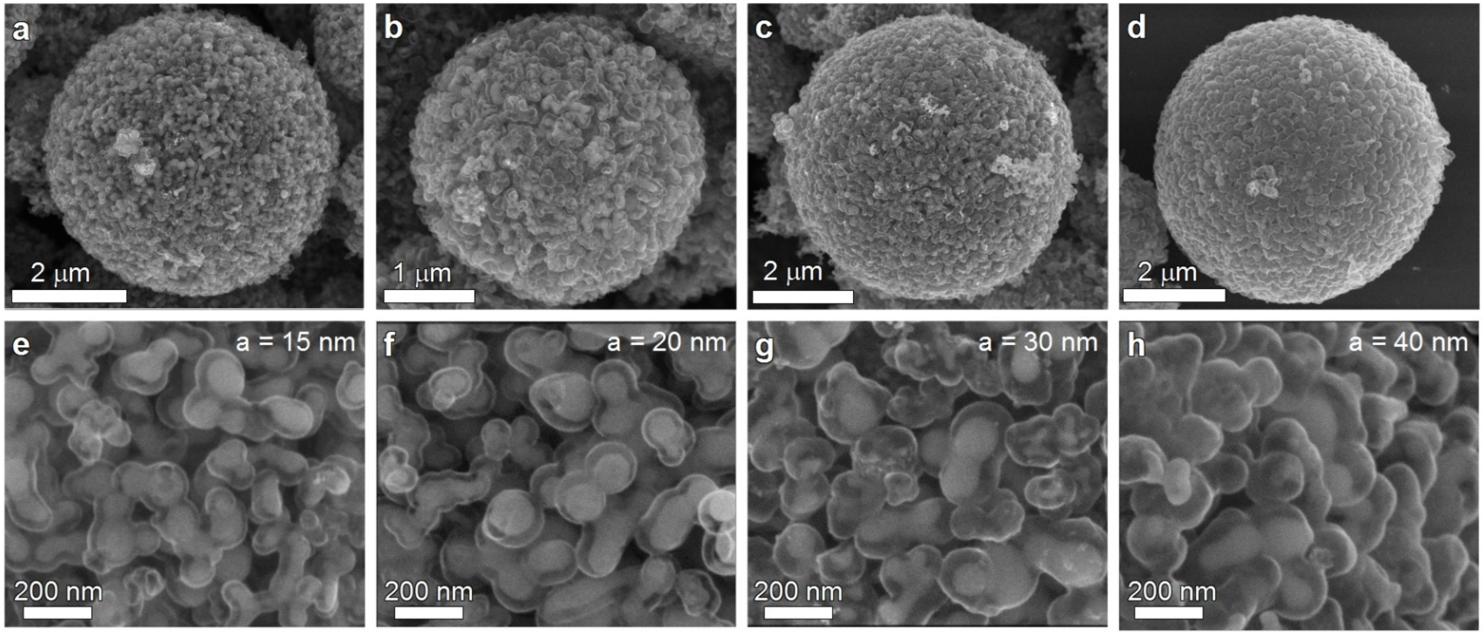
-Preparation and morphology



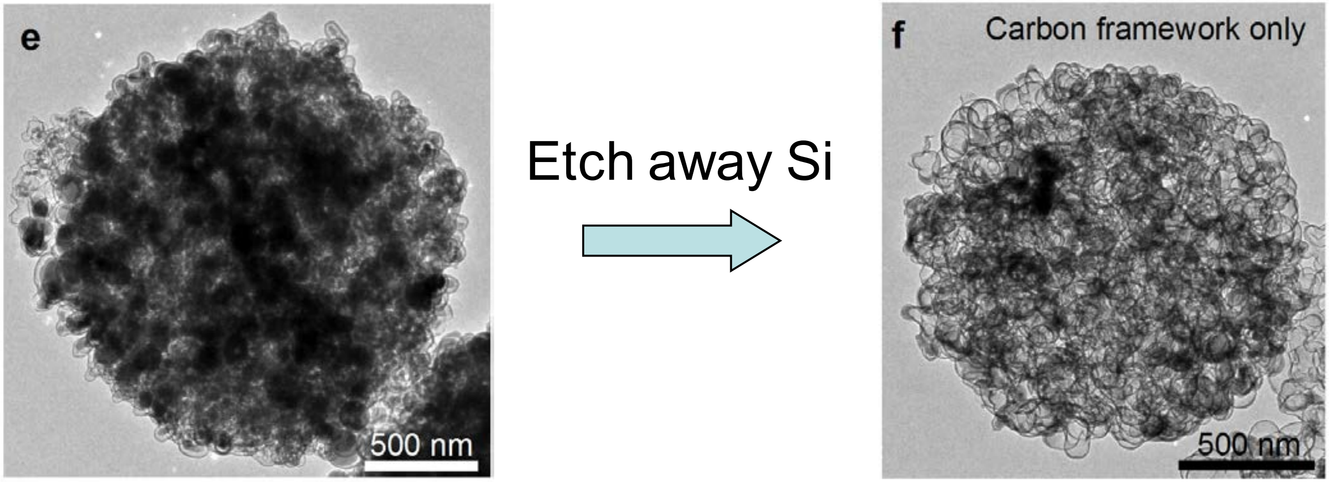


Accomplishment

-Void space control

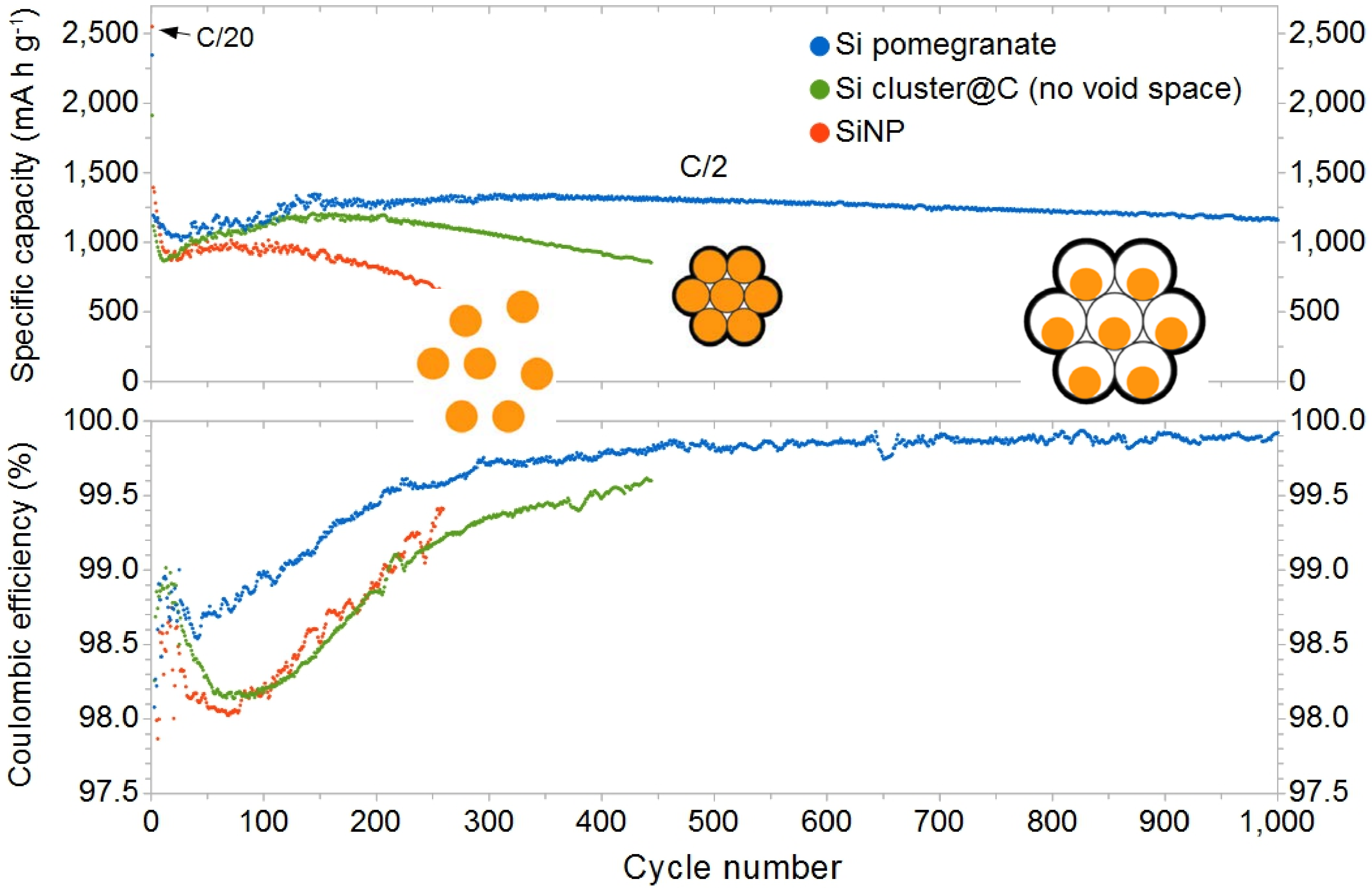


-carbon thickness: ~5-10 nm



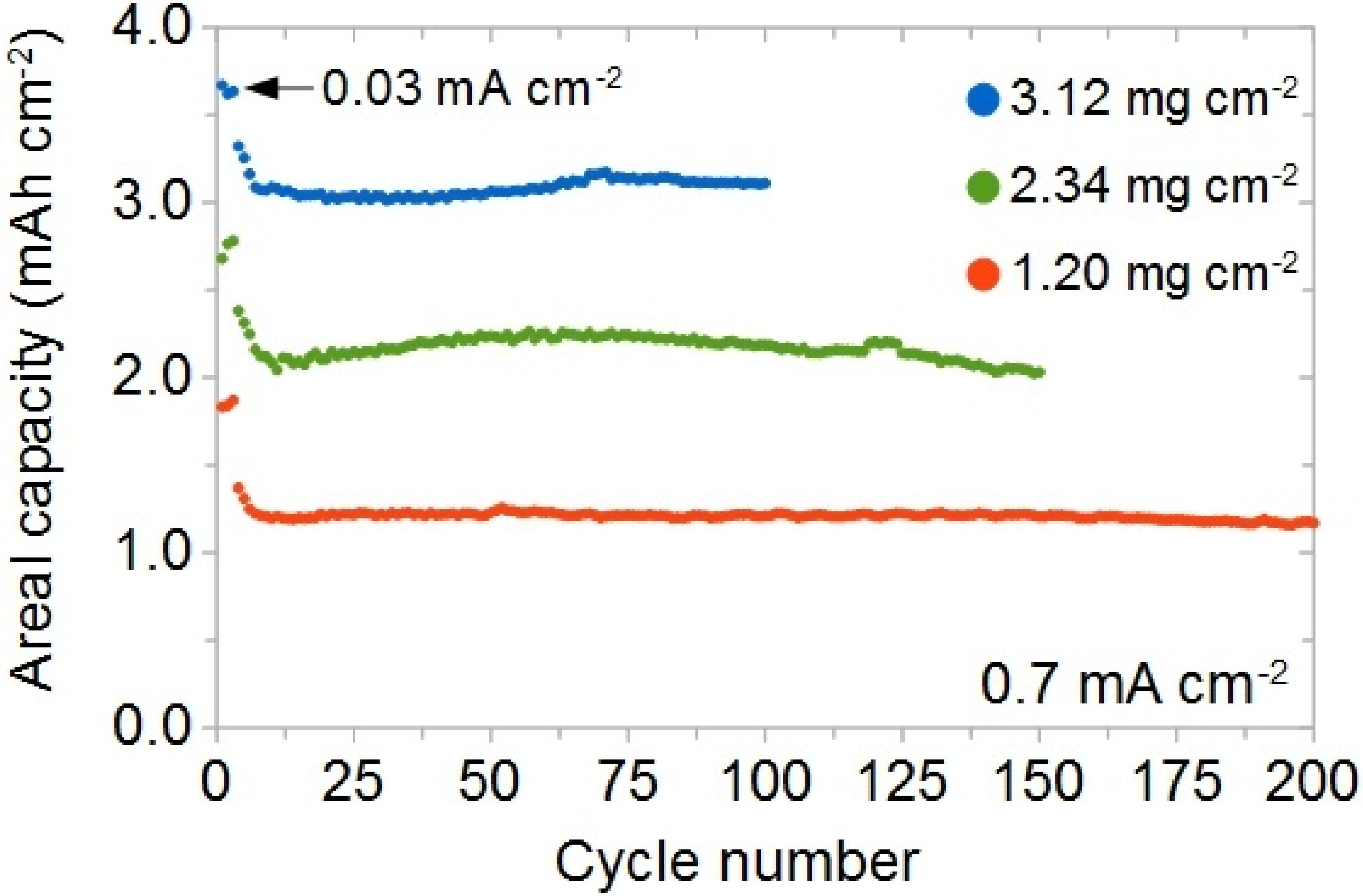
Accomplishment

-Battery performance



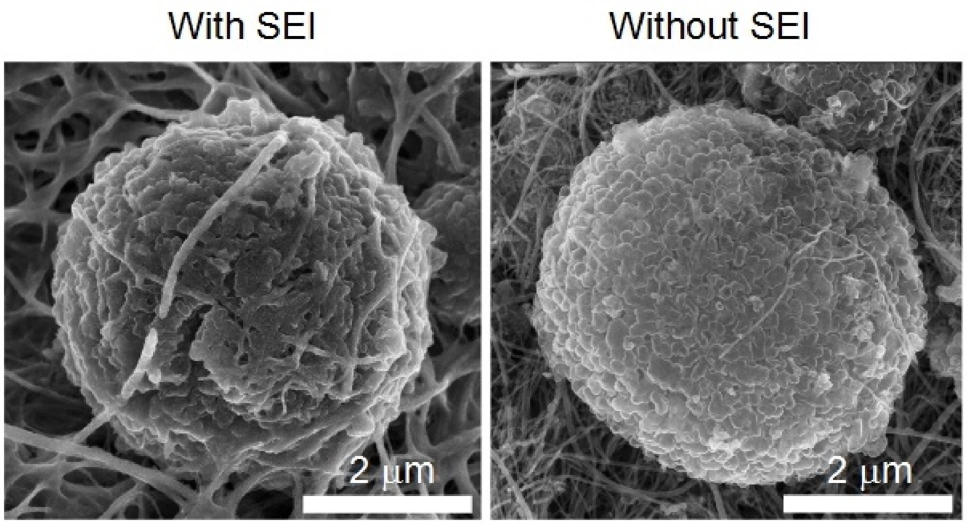
Accomplishment

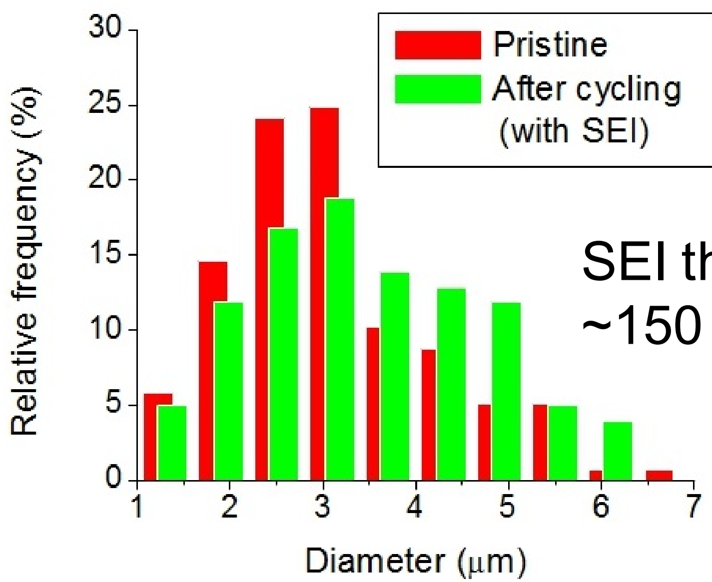
- High areal mass loading



Accomplishment

- Morphology change after cycling

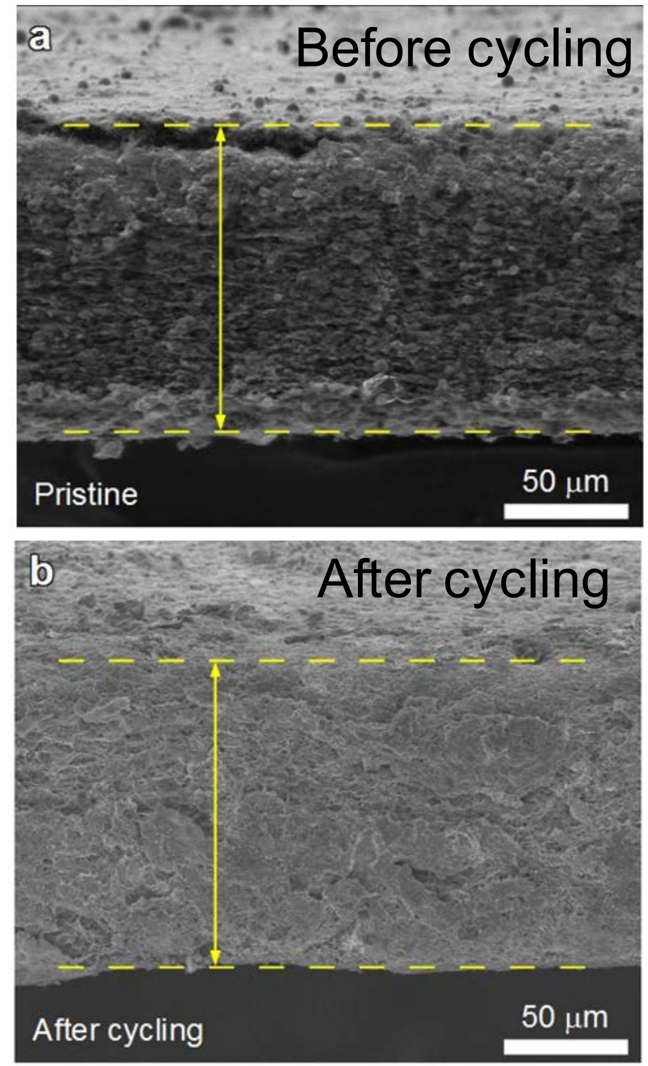




3.1 μm

3.4 μm

SEI thickness: ~150 nm



Collaboration and Coordination

- PNNL: In-situ TEM, Dr. C. Wang
- SLAC: In-situ X-ray, Dr. M. Toney
- UT Austin: Prof. Korgel, a-Si materials
- Stanford: Prof. Nix, mechanics; Prof. Bao, polymer materials
- Companies: Amprius Inc.

Proposed Future Work

- Understand how neighboring particles affect each other and volume changes
- Develop micro-sized Si anodes with long cycle life
- Further understand the nanoscale design to optimize Si anodes, for example, the ratio of Si material dimension vs porosity/hollow space .
- Further develop scalable and low-cost method for synthesizing nano-Si with desired performance.
- Test the Si electrodes with high areal mass loading up to 2-3mg/cm^2.
- Develop surface modification to increase the first cycle coulombic efficiency >90% and improve the later cycle coulombic efficiency.

Summary

- **Objective and Relevance:** The goal of this project is to develop high capacity Si anodes with nanomaterials design to enable high energy batteries, highly relevant to the VT Program goal.
- **Approach/Strategy:** This project combines advanced nanosynthesis, characterization and battery testing, which has been demonstrated to be highly effective.
- **Technical Accomplishments and Progress:** The project has produced many significant results, meeting milestones. They include identifying the fundamental materials design principles, synthesizing and testing, and developing low-cost and scalable methods. The results have been published in top scientific journal. The PI has received numerous invitations to speak in national and international conferences.
- **Collaborations and Coordination:** The PI has established a number of highly effective collaboration.
- **Proposed Future Work:** Rational and exciting future has been planned.